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# The assessment of castings quality using selected quantitative methods

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**Abstract.** Aluminium alloys represent an important category of materials due to their high technological value and wide range of applications. The alloys of the Al-Si-Cu system have become increasingly important in recent years, mainly in automotive industry that uses secondary aluminium (recycled) in the form of various motor mounts, pistons, cylinder heads, heat exchangers, air conditioners due to their high strength at room and high temperature. This work deals with possibilities of quick and correct assessment of aluminium castings microstructure, especially focused on volume, size and shape of structural parameters – eutectic Si and intermetallic phases different chemical compositions. These structural parameters affect the properties of castings and it is important to study their features. The features were studied by using image analyser software NIS Elements.

**Key words** – aluminium castings, image analyser software, quantitative analysis, structural parameters of aluminium cast alloys

## 1. Introduction

The castings quality has been evaluated with different methods of quantitative metallography. In the past (the evaluation of microstructure by etalons, measurement of structural parameters by coherent test grids, and so on.). Nowadays automatic image analysis is mostly used (SKOČOVSKÝ P. 1994)

The automatic image analysis comes from the same principles as the measurement of structural parameters by coherent test grids but this method makes use of the possibilities of a computer for the evaluation of the microstructure. The aim of image analysis is to reduce a considerable amount of data represented by a picture to several significant quantitative values. The image analysis enables the evaluation of different structural parameters, for example the evaluation of volume (area) ratio of phases and structural components, shape of particles, size of particles, count of particles per unit of area or volume, the measurement of distance between particles, length, width, diameter, angle, area or perimeter of particles, orientation of structure etc. in different materials (TILLOVÁ E. 2009, TILLOVÁ E. 2010, KONEČNÁ R. 2008, VAŠKO A. ET AL. 2007, VAŠKO A. 2006).

Inspection and testing of castings encompasses five main categories: casting finishing, dimensional accuracy, mechanical properties, chemical composition and casting soundness. Chemical composition markedly affect the formation of structural parameters in aluminium alloys and these parameters markedly affect the mechanical and fatigue properties. Based on the Al-Si system, the main alloying elements are copper (Cu) or magnesium (Mg) and a certain amount of iron

(Fe), manganese (Mn) and more that are present either accidentally, or they are added deliberately to provide special material properties. These elements partly go into solid solution in the matrix and partly form intermetallic particles during solidification. The size, volume and morphology of intermetallic phases are functions of chemistry, solidification conditions and heat treatment (DOBRZAŃSKI L. A. 2006a, DOBRZAŃSKI L. A. 2006b, DOBRZAŃSKI L. A. 2008, MANIARA R., TILLOVÁ E. 2009, TILLOVÁ E. 2010).

Whereas the quality of recycled Al-Si casting alloys is considered to be the key factor in selecting an alloy casting for a particular engineering application, the quantitative analysis with using software NIS Elements (VAŠKO A. ET AL. 2007, VAŠKO A. 2006, MARTINKOVIČ M. 2010, ULEWICZ R. 2014) was used for control of structural parameters in AlSi6Cu4 cast alloy.

## 2. Experimental material and method

Experiments were performed on AlSi6Cu4 cast alloy which was in three states: (a) as-cast without modification or grain refining; (b) after modification with optimal amount of antimony; and (c) after optimal heat treatment.

The experimental alloy was received in the form of 12.5 kg ingots. Ingots were casted in the foundry laboratory of Technological Engineering Department University of Žilina. The melting process and the modification were carried out in a graphite melting crucible in a resistance oven. For the grain refinement process refining salt AlCuAB6 for experimental material AlSi6Cu4 was used, and the process was carried out while overheating the metal bath to 730°C ± 5°C. Antimony was added to the melt in the form of AlSb10 master in the amount 0.1 wt. % (marked as 0.1% Sb). The optimum heat treatment consist of solution heat treatment at 505°C/6 hours and artificial aging at 170°C/8 hours – marked as T6 (HURTALOVÁ L. 2014). Chemical composition of experimental material is given in Table 1.

Experimental material AlSi6Cu4 alloy has a lower corrosion resistance and is suitable for high-temperature (up to max. 250°C) applications (dynamically exposed casts): pistons, cylinder heat, water-jacket, gearbox and so on (NÁPRSTKOVÁ N. 2013a, NÁPRSTKOVÁ N. 2013b, HANSEN S. C. 2000).

*Table 1. The chemical composition of the AlSi6Cu4, wt. %.*

| *Si* | *Cu* | *Fe* | *Mn* | *Mg* | *Cr* |
|---|---|---|---|---|---|
| *6.52* | *3.88* | *0.43* | *0.45* | *0.29* | *0.01* |
| ***Ni*** | ***Zn*** | ***Ti*** | ***Al*** | | |
| *0.01* | *0.46* | *0.15* | *base* | | |

The samples for metallographic observations (1.5 cm x 1.5 cm) were prepared (wet ground, polished with diamond pastes, finally polished with commercial fine silica slurry (STRUERS OP-U) by standards metallographic procedures. The microstructures were studied using an optical microscope Neophot 32. Samples were etched by standard reagent Dix-Keller, and HF.

Quantitative metallography was carried out on an Image Analyzer NIS - Elements to quantify eutectic Si and intermetallic phases at magnification 500 x.

## 3. Experimental results

Morphology (shape), distribution, volume and size of Si particles markedly affect mechanical properties.

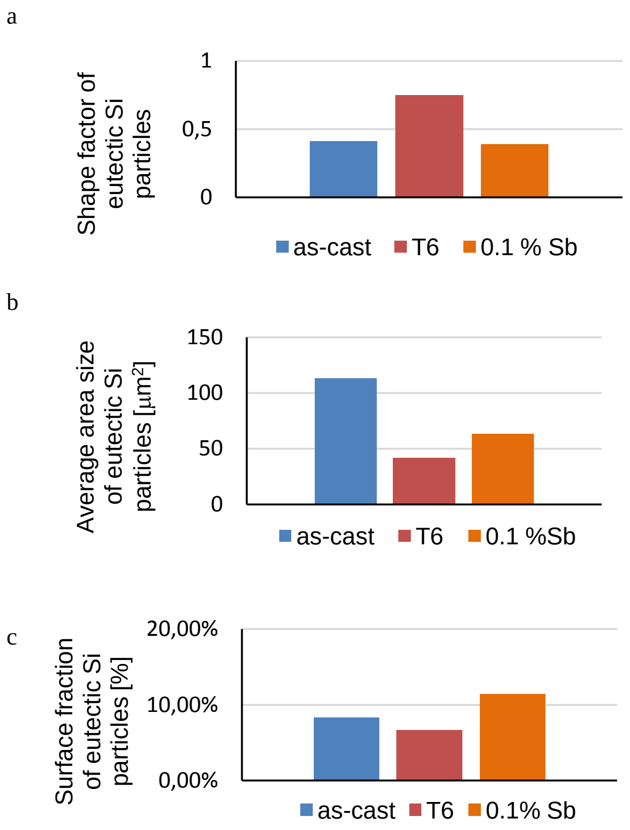


*Fig. 1. Quantitative analysis of eutectic Si particles. (a) shape factor; (b) average area size; (c) surface fraction.*

The experimental quantitative analysis focused on study the area size, surface fraction (volume) and shape factor (morphology) of these particles in order to evaluation the effect of heat treatment and modification (Fig. 1).

The best value of shape factor, which represents perfectly round particles is 1. The experimental results show that the nearest value to 1 has the state after heat treatment of experimental material (0.75 - Fig. 1a). The state after modification (0.39) is comparable with an as-cast state (0.41 - Fig. 1a). The evaluation of area size shows that the minimum area size have the experimental material after heat treatment (42 μm$^2$ – Fig. 1b), than after modification (63 μm$^2$ – Fig. 1b) and in as-cast state the area size was the highest – 113 μm$^2$ (Fig. 1b).

The evaluation of surface fraction shows that the highest is in state after modification (11%) and the lowest is in state after heat treatment (6.7%). The quantitative assessment shows that the best morphology and size of eutectic Si particles is achieved in state after heat treatment, and it is expected that in this state it would have the best mechanical properties, but–the morphology and size of intermetallic phases are very important, too.

From intermetallic phases two types were evaluated: Cu-rich – ternary eutectic and Fe-rich – skeleton like. These two types of intermetallic phases were observed in microstructure of experimental material (HURTALOVÁ L. 2015, TILLOVÁ E. 2009, TILLOVÁ E. 2010).

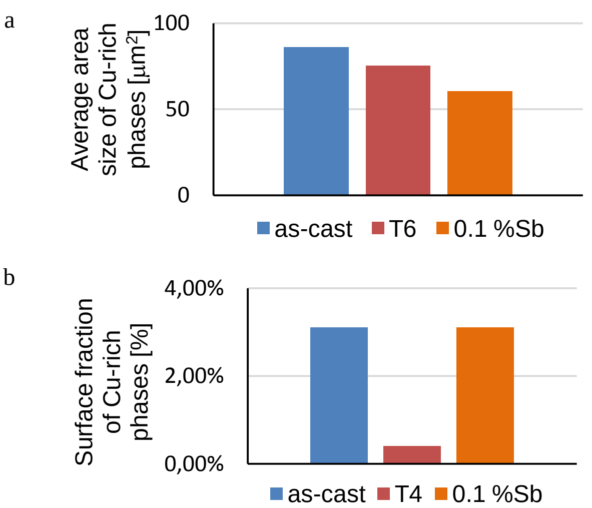


*Fig. 2. Quantitative analysis of Cu-rich intermetallic phases. (a) average area size; (b) surface fraction.*

The evaluation of intermetallic phases ~~was~~ focused on study their area size and surface fraction (volume) in order to evaluation the effect of heat treatment and modification (Fig. 2, 3).

The quantitative assessment of Cu-rich phases shows that minimum average area size was after modification 60.5 μm$^2$ (Fig. 2a). In state after heat treatment area size was 75.4 μm$^2$ and in as-cast state 82 μm$^2$. The surface fraction was minimum after heat treatment 0.4% and in as-cast state and state after modification was the same 3.1% (Fig. 2b). The assessment of Cu-rich phases shows that Cu-rich phases were fragmented and dissolved in to the matrix in the state after heat treatment the most and, therefore, it is supposed that a material in this state would have the best mechanical properties (TILLOVÁ E. ET AL. 2009).

The quantitative assessment of Fe-rich phases shows that the minimum average area size was after modification 35 μm$^2$ (Fig. 3a). In state after heat treatment was area size 72 μm$^2$ an in as-cast state 106 μm$^2$. The modification caused a significant changes of Fe-rich intermetallic phase's size. The surface fraction was minimum after modification (2.9%) an in as-cast state (2.7%) (Fig. 3b). The maximum surface fraction of Fe-rich phases was after heat treatment (4.4%). The assessment of Fe-rich phases shows that these phases were fragmented and coarsened in state after modification the most (TILLOVÁ E. ET AL. 2010).

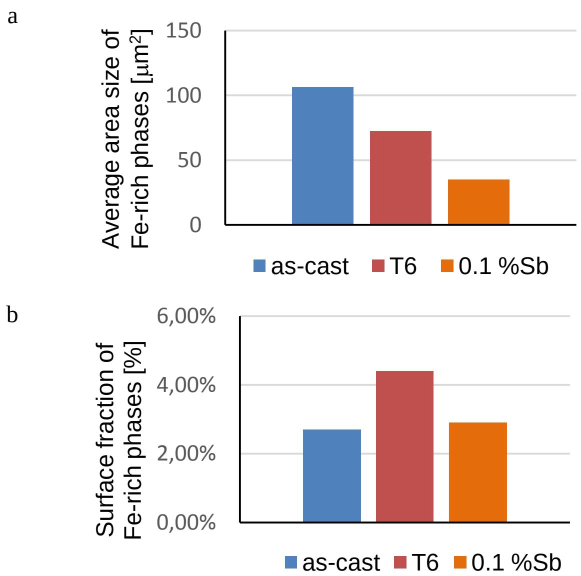


*Fig. 3. Quantitative analysis of Fe-rich intermetallic phases. (a) average area size; (b) surface fraction.*

# 9. Summary and conclusions

The quantitative assessment by using image analyser software NIS Elements was used for study the size, volume and morphology (shape) of structural parameters (Si particles, Fe-rich and Cu-rich intermetallic phases) in experimental material AlSi6Cu4.

The evaluations shows that this material has the large eutectic Si particles, Cu-rich and Fe-rich intermetallic phase in as-cast state. This morphology is insufficient because the mechanical properties affect these particles, therefore material was heat treated or modified.

The average area size of all particles was decreasing while using heat treatment and modification. The results show~~s~~ that heat treatment has a greater effect on area size of eutectic Si particles and modification on intermetallic phases. Therefore, it is best when these methods are used together.

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